

GNSS GUIDANCE AND MACHINE CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of and claims the benefit of: U.S. patent application Ser. No. 12/355,776, filed Jan. 17, 2009, which is a continuation-in-part of Ser. No. 12/171,399, filed Jul. 11, 2008, which is a continuation-in-part of Ser. No. 10/804,758, filed Mar. 19, 2004; now U.S. Pat. No. 7,400,956, which is a continuation-in-part of application Ser. No. 10/828,745, filed Apr. 21, 2004; and U.S. Provisional Patent Applications No. 60/456,146, filed Mar. 20, 2003 and No. 60/464,756, filed Apr. 23, 2003. The contents of all of the aforementioned applications are incorporated by reference herein in their entireties.

BACKGROUND OF THE INVENTION

[0002] This invention relates generally to machine control using global navigation satellite systems (GNSSs) and more particularly to an earth-working equipment control system and method.

[0003] Movable machinery, such as excavators, graders, agricultural equipment, open-pit mining machines, aircraft crop dusters and other mobile operating equipment can benefit from accurate positioning using global navigation satellite systems (GNSSs). For example, U.S. Pat. No. 7,689,354, which is assigned to a common assignee herewith, discloses, agricultural equipment equipped with an adaptive guidance system including a multi-antenna GNSS system for guidance, automatic steering, independent implement positioning and spraying control.

[0004] In the earth-moving field, a wide variety of equipment has been used for specific applications, such as excavators, backhoes, bulldozers, loaders and motor graders. Earth-moving projects encompass a wide variety of excavating, grading, trenching, boring, scraping, spreading and other tasks, which are performed in connection with road-building, infrastructure improvements, construction, mining and other activities. Such tasks are typically performed by specialized equipment. Such equipment can be relatively sophisticated and can handle relatively high capacities of materials.

[0005] Mobile earth-moving equipment is steered and otherwise guided within jobsites. Moreover, the working components of such equipment, such as blades, drills, buckets and ground-engaging tools, are controlled through their various ranges of motion. Machine guidance and control were conventionally accomplished by human operators, who often needed relatively high levels of skill, training and experience for achieving maximum production with the equipment. For example, jobsite grading was typically accomplished by surveying the site, placing stakes at predetermined locations to indicate the locations of “cutting” (i.e. earth removal) and “filling” (i.e. earth placement) operations required to achieve a final grading plan. Cut and fill quantities are preferably balanced as much as possible to avoid added expenses for additional fill material or removing excess material.

[0006] In addition to balancing material requirements, design parameters such as water runoff, slope, compaction (relating to load-bearing capacity) and thicknesses of various material layers are important grading and site design criteria. Previous earth-moving machinery tended to be highly reliant on operator skill for achieving desired final results.

[0007] The present invention uses satellite positioning systems (SATPSs), such as the Global Positioning System (GPS) and other global navigation satellite systems (GNSSs) for guidance and machine control. Project bidding can thus be based on more precise labor, material quantity, fuel, equipment maintenance, material disposal, time and other cost factors. Project expenses can thus be reduced by controlling input costs of material, material hauling, fuel, labor, equipment utilization, etc. Still further, earth-moving operations that were previously conducted in separate “rough” and “fine” phases can be combined into single-phase procedures due to the greater efficiencies and accuracies achievable with the GNSS machine guidance and control of the present invention. Still further, operators tend to be less fatigued with a relatively high level of automated machine guidance and control, as opposed to manually-intensive control procedures requiring high degrees of concentration and operator interaction.

[0008] Various navigation and machine control systems for ground-based vehicles have been employed but each has disadvantages. Systems using Doppler radar encounter errors with the radar and latency. Similarly, gyroscopes, which may provide heading (slew), roll, or pitch measurements, may be deployed as part of an inertial navigation package, but tend to encounter drift errors and biases and still require some external attitude measurements for gyroscope initialization and drift compensation. Gyroscopes have good short-term characteristics but undesirable long-term drift characteristics, especially gyroscopes of lower cost such as those based on a vibrating resonator. Similarly, inertial systems employing gyroscopes and accelerometers have good short-term characteristics but also suffer from drift.

[0009] Providing multiple antennas on a vehicle can provide additional benefits by determining an attitude of the vehicle from the GNSS ranging signals received by its antennas, which are constrained on the vehicle at a predetermined spacing. For example, high dynamic roll compensation signals can be output directly to the vehicle steering using GNSS-derived attitude information. Components such as gyroscopes and accelerometers can be eliminated using such techniques. Real-time kinematic (RTK) can be accomplished using relatively economical single frequency L1-only receivers with inputs from at least two antennas mounted in fixed relation on a rover vehicle. Still further, moving baselines can be provided for positioning solutions involving machine components and multi-vehicle/machine GNSS control.

[0010] GNSS-based equipment and methods can also be used for machine control, such as earth-moving equipment. GNSS guidance can provide a relatively high level of accuracy. For instance, prior to GNSS guidance and machine control, earth-moving operations tended to rely more on operator skill for manually spot-checking grade elevations in order to smoothly cut and fill a plot of land to a particular height. With the GNSS guidance and machine control of the present invention providing three-dimensional (3D) positional tracking, earth-moving equipment can perform cut, fill, and other earth-moving functions using GNSS positioning data for greater repeatable accuracy and operating efficiencies. Although GNSS-based control techniques have been used in earth-moving machinery, previous GNSS machine control systems used in such equipment do not provide the advantages and features of the present invention.

[0011] By using GNSS-equipped earth-moving machines, the need for manual grade checks can be reduced or elimi-